THE AMAZON RIVER BREEZE AND THE LOCAL
BOUNDARY LAYER: II. LINEAR ANALYSIS
AND MODELLING

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Abstract. Observed boundary-layer circulations close to the confluence of the Negro and Solimões
rivers near Manaus in the Brazilian equatorial Amazon forest were presented in Part I. These are
shown through linear analysis and second-order turbulence modelling to be aspects of a river breeze
superimposed on the basic flow. Linear analysis is presented to estimate the spatial structure and
intensity of a breeze induced by a river with width and thermal contrast similar to that observed in
the central Amazon. It is found that observed thermal contrasts are sufficient to produce a river breeze
that can be perceived more than 20 km inland daily. A one-dimensional second-order closure model
is used to show that observed nocturnal low-level wind maxima and diurnal surface wind rotation are
aspects of a river breeze interacting with the seasonally-varying mean flow. At night, partial decoupling
of the surface from the lower atmosphere allows the land breeze to be expressed as a low-level wind
maximum. During the day, convective mixing communicates upper level winds to the surface during
rapid morning boundary-layer growth. Rotation of the surface wind follows as the river breeze circu-
lation is then superimposed.

1. Introduction

Analysis of data from the Amazon Boundary Layer Experiments (ABLE-2a and
ABLE-2b, Harriss et al., 1988, 1990) indicated the presence of several features of
the PBL in the central Amazon near the large rivers (Oliveira and Fitzjarrald,
1992, Part I, hereafter OF): (1) Circulations confined to the first 500 m exhibiting
nocturnal flow toward the river reversing in the daytime; (2) A diurnal oscillation
in the horizontal pressure and temperature gradients as well as in the divergence
near the surface; (3) Rotation of the surface wind direction through the day,
with the average wind vector describing approximately elliptical trajectories; (4)
Boundary-layer wind maxima formed predominantly during the transition period
(0600–0900 LT) in the 1985 dry season and during the night in the 1987 wet season.
Two classes of low level wind maxima were identified. The first, observed at the
first 200–400 m above the surface is characterized by low level wind maxima of
2–6 m/s with significant wind directional shear, and a second class observed within
the first 400–600 m, with intensity 10–15 m/s, exhibiting little directional shear.
Since dry-season aircraft measurements indicated a daytime thermal contrast between the Negro River and the surrounding forest to be approximately +6 °C during the day and −3 °C at night, the existence of a river breeze circulation seemed likely.

Boundary-layer wind maxima and jets can be explained by several mechanisms: (1) Inertial oscillation (Blackadar, 1957); (2) Thermal contrast produced by a sloped surface (McNider and Pielke, 1981); (3) Topographic effects produced by a flow forced above the barrier (DeSouza et al., 1971; Hsu, 1979a); and, perhaps, (4) Transient pressure gradients associated with clouds. As Oliveira (1990) and Greco et al. (1992) have noted, none of these mechanisms is appropriate for understanding equatorial boundary-layer wind maxima. The inertial period at Manaus (3° S, site of the experiments) is about 5 days, and the first mechanism is ruled out. Topographic effects are confined to the extreme west and northern parts of the Amazon basin. The terrain elevation along the longitude at 60° W starting near Manaus rises gently 100 m above the MSL to approximately 200 m height at 4° N (Oliveira, 1990). At this longitude, the slope of the terrain is 1:2300 between 3° S and 4° N, where it abruptly increases from 300 to 600 m, well below the Great Plains terrain slope of 1:800 (Wexler, 1961). The horizontal pressure gradient estimated by assuming the buoyancy acceleration proportional to the vertical gradient of potential temperature times the elevation of the terrain is approximately two orders of magnitude lower than the horizontal pressure gradient observed at the surface (OF).

Another possible mechanism responsible for the observed afternoon evolution of boundary-layer winds and low-level wind maxima would be a circulation induced by preferential inland cloud formation. It is conceivable that the cloud-induced horizontal pressure gradients might also provoke jets similar in structure to those produced by a river breeze circulation. Scala et al. (1989) found that a mature Amazonian squall line can induce a horizontal pressure gradient equivalent to the amplitude of the diurnally-varying pressure gradient observed at the surface (OF). Similar order-of-magnitude estimates for the horizontal pressure gradient were obtained by Lemone et al. (1988). We cannot rule out this origin for the jet-like circulations, but we note that the jet wind direction would not be fixed geographically as was observed. A better answer awaits a more complete numerical simulation; we believe that cloud forcing is probably a consequence of river breeze triggering.

In this paper we examine the hypothesis that the presence of river breeze forcing associated with the wide rivers of the central Amazon region is a plausible explanation both for the nocturnal low level circulations and for the diurnal clockwise rotation of the surface wind vector that is observed (OF). The idea is that these diurnal patterns result from the cooperative effects of river breeze forcing and boundary-layer mixing. Our method is both analytic and numerical.